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InGaAs resonant cavity light emitting diodes (RC LEDs)

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Abstract. We have developed technology of resonant-cavity light emitting diodes (RC LED) with very good emission characteristics. RC LED spectrum is determined mainly by the cavity resonance and is concentrated into a narrow line with 1.3 nm halfwidth. The directionality of RC LED emission depends on the tuning between QW emission and cavity resonance.

Introduction

In recent years a number of optoelectronic devices employing microcavity structures were proposed. Such devices benefit from utilization of specific effects resulting from placing the active structure inside the Fabry–Perot type microcavity. The most notable examples of such devices are Resonant Cavity Light Emitting Diodes (RC LED) realized in the early nineties [1]. The main advantages of resonant cavity LEDs over conventional devices are higher emission intensities, higher spectral purity and more directional emission patterns. In conventional LEDs it is difficult to achieve high quantum efficiencies. High difference between the refractive index of GaAs and the air results in low critical angle and extraction efficiency of the order of 2% for isotropic light source. On the other hand in RC LED external quantum efficiencies in excess of 20% have been reported [2]. All above mentioned features make RC LEDs attractive alternative for lasers in many applications.

1. RC LED design and technology

The RC LED cavity is constructed normal to the substrate plane by stacking multilayer films including an active region, spacer and two dielectric mirrors. Such a structure forms a one-dimensional Fabry–Perot cavity resonator. A dielectric mirror is formed with a periodic stack of quarter wavelength thick layers of alternating high and low refractive index material and is referred to as a distributed Bragg reflector (DBR). The active region consists of a spacer layer of the thickness equal to integer multiple of the half wavelength and of one or several quantum wells (QWs). The quantum wells are situated at the antinodes of the standing wave pattern. Such configuration of the microcavity offers possibility of controlling the spontaneous emission in the structure, and in particular allows for enhanced coupling of the spontaneous emission into the cavity mode [3, 4].

The optimisation of the microcavity requires proper tuning of the wavelength of radiation emitted from the active region, the peak reflectivity of the DBRs, and the cavity resonance. This is the reason why the structure performance is very sensitive to the variations in thickness of the layers and their composition. The wavelength of radiation from the QW depends on both the composition and thickness. The spectral shape of the reflectivity of DBRs in the case of GaAs/AlAs reflectors depends on the layer thickness in the mirrors. Similarly, the position of the cavity resonance depends on the thickness of the spacer layers between the mirrors and the QW region and the phase of the reflection from the mirrors. Thus, the optimum performance of the structure requires simultaneous alignment

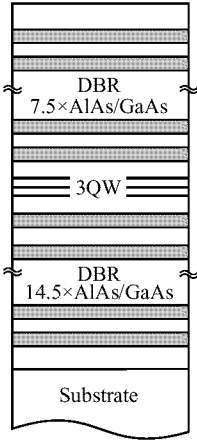


Fig. 1. Schematic RC LED structure with InGaAs 3 QW active region, designed for operation at 1000 nm.

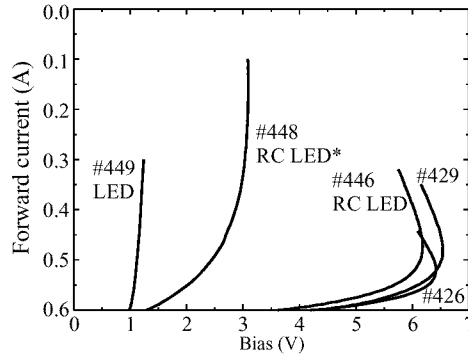


Fig. 2. I–V characteristics of RC LED structures with different DBR reflector design.

of all three features [5]. The goal in growing the mirrors for RC LED is to get the layers each approximately a quarter wavelength thick and to get the reflection band centered at the right wavelength range. The position of the cavity resonance determines the diode emission wavelength. The RC LED operation relies on enhanced spontaneous emission occurring in microcavity structures.

The RC LED structures studied in this work were fabricated by MBE. The schematic view of a typical structure is shown in Fig. 1. The active region consists of λ -type cavity with either 1 or 3 InGaAs QWs, each 80 Å thick, separated by 100 Å GaAs barriers. The devices were designed for the emission at $\lambda = 1000$ nm. The structure #426 is a high Q (quality factor) microcavity with single quantum well. The structures #446, #448 have lower number pairs of quarter-wavelength layers in the reflectors and consequently lower Q . They also have 3 QW active region. The structures #426, #446 have abrupt GaAs/AlAs interfaces in DBR reflectors, whereas in the case of the structure #448, 20 nm thick $\text{Al}_{0.5}\text{Ga}_{0.5}\text{As}$ layers were inserted in between GaAs and AlAs layers to lower DBR resistivity. The reference structure #449 of conventional LED without DBR reflectors has been grown for the sake of comparison. After MBE growth wafers were tested by photoluminescence mapping and reflectivity, in order to select material meeting device requirements before further processing.

The diodes were fabricated by conventional photolithography and metalization process. The light from the diode is extracted through the openings in the upper Cr-Pt contact. The bottom Au-Ge contact (to the n-type substrate) formed a solid circle. The diodes were electrically tested at probe tester and good ones were assembled in high frequency microwave type cases. Generally we have found very good correlation between the results of optical tests on as grown wafers and probe tests on final devices.

2. RC LED characteristics

The assembled diodes were subjected to electrical and optical tests. The I–V characteristics of the diodes are shown in Fig. 2. The series resistance of the diodes fabricated from

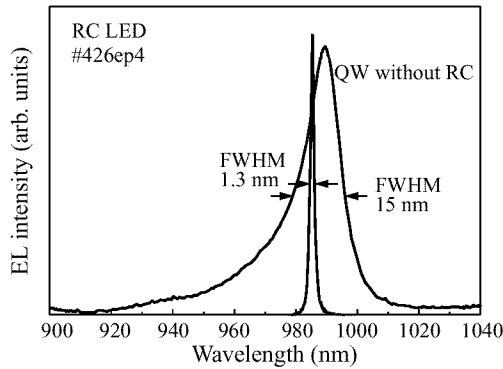


Fig. 3. Emission spectrum of RC LED compared to conventional LED.

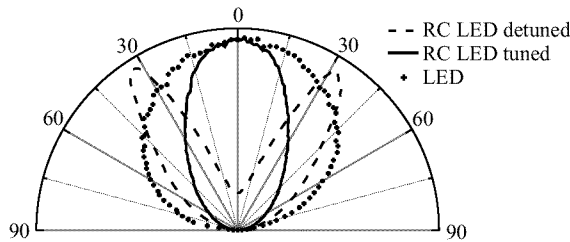


Fig. 4. Angular spectrum of RC LED compared to conventional LED.

wafer #448, although still higher than the one for reference diode without microcavity is acceptable. The diodes made of wafers #426, #446 with abrupt DBRs show up to 3 times higher resistance and roll-over of I-V characteristics due to the heating. We have found that DBR profile even stronger influences diode resistivity than does the number of pairs of the layers.

The emission properties of RC LED and conventional LED are shown in Fig. 3. In both cases the spectra have been collected from the small solid angle and sent by an optical fiber to the spectrometer. Comparing to classical LED the spectrum of RC LED is concentrated into a narrow line with 1.3 nm halfwidth. The shape of LED spectrum reflects thermal distribution of electrons and holes in the conduction and valence bands. On the other hand the RC LED spectrum is determined mainly by the cavity resonance; its width decreases with the increase of the cavity finesse Q and the intensity increase reflects the on-axis cavity enhancement. The figure of merit of LED used in optical fiber communication systems is the photon flux density emitted from the diode at a given current, for a given wavelength. Since the optical power coupled into a fiber is directly proportional to the photon flux density the RC LEDs are particularly suitable for fiber link applications. The higher spectral purity of RC LED reduces also chromatic dispersion in optical fiber communications. Additional, favorable RC LED property is its emission characteristic directionality which depends on the tuning between QW emission and cavity resonance. The angular characteristics of RC LED emission for perfectly tuned and substantially detuned diodes are shown in Fig. 4. Also included is the angular characteristic of conventional LED. The frequency of the cavity resonance depends on the angle of observation, which means that emission line shifts to shorter wavelengths with increasing angle between the direction of observation and the normal to the surface. Nevertheless at any angle this is a narrow line in contrast to conventional LED. That is we have spectral concentration in all directions. The RC LEDs

can indeed be very bright. In principle the enhancement of the spontaneous emission inside the cavity and emission through one of the mirrors out of the cavity can be very different. For very high finesse cavities, which are typical for VCSELs the overall emission out of the cavity can decrease (in the limit of very high reflectivity $R = 100\%$ the emission out of the cavity becomes zero). At moderate values of the Q factor, which are characteristic for RC LEDs the spontaneous emission both inside and out of the cavity can be enhanced even by more than an order of magnitude [6].

3. Conclusions

We have demonstrated reproducible growth of microcavities and in particular we have developed technology of resonant-cavity light emitting diodes (RC LED) with very good emission characteristics. RC LEDs proved to be more tolerant to the epitaxial growth parameters and device fabrication procedures than VCSELs. As relatively robust devices they are less sensitive to typical for VCSEL manufacturing challenges and seem to have great potential for commercialization. The problems which are still to be solved, before the technology can be regarded as fully mature are wafer uniformity, yield and reliability of the devices. Nevertheless even at the moment there is no doubt that resonant cavity enhanced devices will have a profound impact on optoelectronic systems.

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References

- [1] M. S. Unlu and S. Strite, *J. Appl. Phys.* **78**, 607 (1995).
- [2] H. Benisty, H. De Neve and C. Weisbuch, *IEEE J. Quantum. Electron.* **34**, 1612 (1998).
- [3] T. Baba, T. Hamano, F. Koyama and K. Iga, *IEEE J. Quantum. Electron.* **27**, 1347 (1991).
- [4] T. J. Ochalski, J. Muszalski, M. Zbroszczyk, J. Kubica, K. Reginski, J. Katcki and M. Bugajski, *NATO Science Series, 3. High Technology, Optical Properties of Semiconductor Nanostructures*, M. L. Sadowski et al. (eds.) **81**, 201 (2000).
- [5] K. Reginski, J. Muszalski, M. Bugajski, T. Ochalski, J. M. Kubica, M. Zbroszczyk, J. Katcki and J. Ratajczak, *Thin Solid Films* **367**, 290 (2000).
- [6] N. Hunt, E. F. Schubert, R. A. Logan and G. J. Zydzik, *Appl. Phys. Lett.* **60**, 921 (1992).